Search notes

10/777,014

1-46 cancelled

conduit

2 (w)

139 (w) method

93 (w) position and controller time

140 (w) method

94 (w) – 95

96 method

97

98

99

100 – 101 – 102

103

104

105

106

107 – 108

109 – 111

110 – 112

113

114

115

116

117 – 118

119 – 120 –

121

122

123

124

125

126

127

128

129

130

131

132

133

134

135

136

137 – 138

(w)

EXA PEND

47 – 48

49

50

51

52

53 – 54 – 55

56

57

58

59

60 61

63 (w)

EXA PEND

66

67

68

69

70 – 71

72 – 73

74

75

76

77

78 – 79

80 (w)

81 (w)

82 (w)

83 (w)

84 (w)

85 (w)

86 w

87 (w)

88 (w) – 89 (w)

90 (w)

91 (w)

142 (w)

143 (w) – 144 (w)

EXA PEND

141 Amended – 62 – 64 (w)

65 (w)

145

146 – 147

Search notes For 10/777,014

BACK TO BASICS - ULTRASONICS

1 BASIC PRINCIPLES OF SOUND

Sound waves are vibrations of the particles of solid liquid or gas through which the sound is passing. Each particle oscillates about a mean position and in doing so causes a similar vibration to be taken up by its neighbour. The resulting disturbance radiates out from the source as a sound wave.

Sound waves are therefore a form of mechanical energy that can only exist in a solid liquid or gas and not in a vacuum. Essentially, there are two requirements for sustaining a vibration: there must be something to vibrate and some force that will always try to return that 'something' to its original position. In other words, there must be MASS and ELASTICITY. This is illustrated in figure 1.1a below. A weight is suspended from a beam by a spring. The weight (W) provides the MASS and the spring provides the ELASTICITY. At rest, the force of gravity (G) acting on the weight is balanced by the tension (T) in the spring.

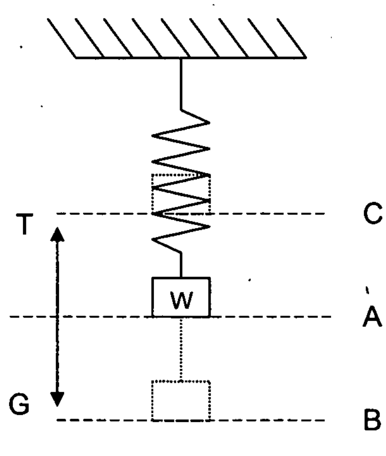

Fig. 1.1a

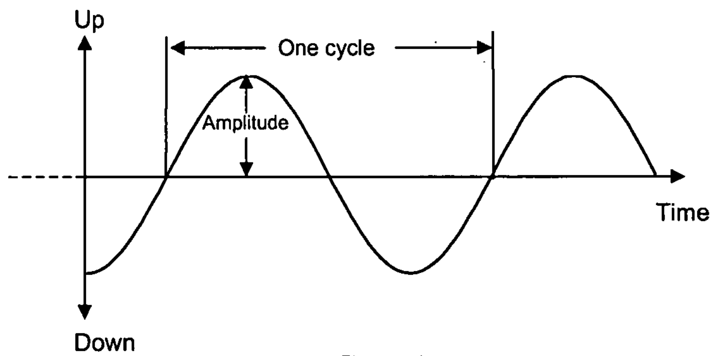

Fig. 1.1b

If the weight is pulled downwards from its rest position (A) to position B, the tension in the spring will increase. When the weight is released, the weight will accelerate back towards position A reaching its maximum velocity at position A when the forces T and G are again equal. The momentum of the weight travelling at speed will cause the weight to overshoot position A. Immediately the tension in the spring is less than the force of gravity and the weight will begin to decelerate until it comes to rest at position C. Because force G is now larger than T, the weight will start to descend again; overshooting position A again until the increasing tension in the spring eventually stops the downward movement. At this time, the whole cycle of events starts again and continues until friction and air resistance losses gradually bring the oscillations to a stop.

Figure 1.1b is a graph of the displacement of the weight, during this up and down motion, against time. In the diagram, two points on the graph are shown where the weight is doing the same thing, travelling upwards and passing through position 'A' on consecutive passes. The distance (time) between these two points represent one complete cycle of the oscillation. The number of cycles of oscillation completed in a given period of time (usually one second) is called the 'Frequency' of the oscillation. The maximum displacement of the weight from its normal rest position is called the 'Amplitude' of the oscillation.

One of the best examples of an oscillating source of sound that can be used later in describing the action of an ultrasonic test probe is the guitar. The strings of a guitar are elastic and pre-tensioned to produce a particular frequency of vibration. Each string is distorted by the guitarist to stretch the string and then released. As soon as it is released, the string begins to oscillate about its mean position at the resonant frequency of that string. Shortening the string using a finger to hold the string against one of the frets can change the frequency. The human ear recognises the frequency as the 'Pitch' of the note produced. The 'Loudness' of the note depends on how far the guitarist distorted the string before t was released, in other words, the 'Amplitude' of that distortion.

The mass of woodwork to which the string is attached amplifies the sound and adds its own harmonic frequencies to produce a range of notes to give the characteristic richness of tone to the instrument. The band of frequencies produced is called the 'Bandwidth' of the sound in ultrasonics.

THE ACOUSTIC SPECTRUM

Sound waves are described above as the oscillation of particles of solids, liquids or gases. The human ear can only detect a small range of possible vibration frequencies, roughly between 16 cycles per second and 20,000 cycles per second. In theory, however, there is a limitless spectrum of frequencies and that are possible even if humans can't hear the whole range. The spectrum is illustrated in figure 1.2 below: -

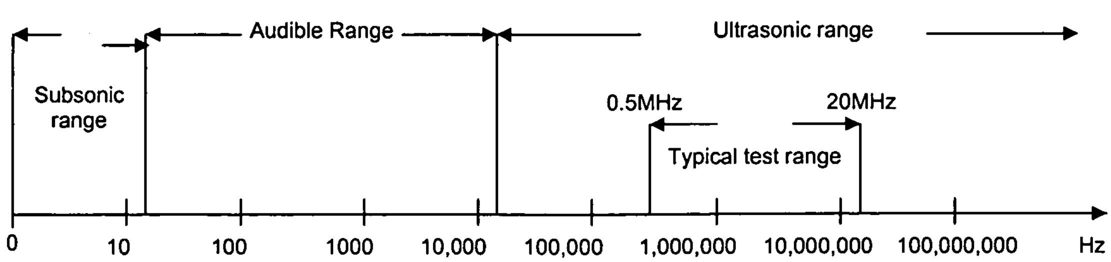

Fig. 1.2 Acoustic Spectrum

The unit used to denote frequency is the Hertz, abbreviated as Hz, where 1Hz is one cycle per second. One thousand Hz is written as 1KHz (Kilo Hertz) and one million Hz as 1MHz (Mega Hertz). The part of the spectrum from zero to 16Hz is below the range of human hearing and is called the

'Subsonic', or 'Infrasonic' range. From 16Hz to 20KHz is known as the 'Audible' range and above 20KHz as the 'Ultrasonic' range. Ultrasonic flaw detection uses vibrations at frequencies above 20KHz.

Most flaw detection takes place between 500KHz and 20MHz although there are some applications, for example in concrete, that use much lower frequencies and there are special applications at frequencies above 20MHz. In most practical applications in steels and light alloys, frequencies between 2MHz and 10MHz predominate. Generally the higher the test frequency, the smaller the minimum detectable flaw, but it will be shown in following articles that higher frequencies are more readily attenuated by the test structure. Choosing an appropriate test frequency becomes a compromise between the size of flaw that can be detected and the ability to get sufficient sound energy to the prospective flaw depth.

MODES OF PROPAGATION

Sound energy travels, or 'propagates', outwards from the source of the vibration as the oscillation of a particle of solid, liquid or gas disturbs the neighbouring particles so that the neighbour takes up the oscillation. It will take time for the disturbance, called the 'sound wave', to reach a given distance from the source. This is a measure of the velocity of sound in a given medium. It will be shown that this velocity varies with the characteristics of each material and the way in which the disturbance is transmitted from one particle to the next. The different ways in which the disturbance may be transmitted are known as the 'Modes of Propagation'.

The different modes of propagation come about because solids, unlike liquids and gases, have a modulus of rigidity as well as a modulus of elasticity. Solids Liquids and gases all show resistance to compressing or stretching. In the case of solids we refer to this resistance as Young's Modulus of Elasticity ('E') for the material. The elasticity of a solid is plotted when a tensile test is carried out and from the resulting graph the 'Ultimate Tensile Strength' (UTS) of the material can be derived. The Modulus of Rigidity ('G') is the material's resistance to a shear load.

COMPRESSION WAVE MODE

Because liquids and gases have no modulus of rigidity, sound waves can only propagate by using their resistance to tension and compression. This type of sound wave is called the 'Compression Wave'. Compression waves can exist in solids, liquids and gases because they all have elasticity. Compression waves are also known as 'Longitudinal' waves, and sometimes as 'Plane' waves The individual particles of the solid liquid or gas oscillate about their mean position, and **the direction of propagation of the compression wave is in the same plane as the particle motion** as shown in figure 1.3.

Fig. 1.3

SHEAR WAVE MODE

Shear waves only exist in solids and rely on the modulus of rigidity of the solid under test, they can exist on their own or co-exist with compression waves and surface waves. Shear waves are also sometimes called 'Transverse' waves. Again, the individual particles of the solid oscillate about their mean position, but **the direction of propagation of the shear wave is at right angles to the particle motion.** This is illustrated in figure 1.4.

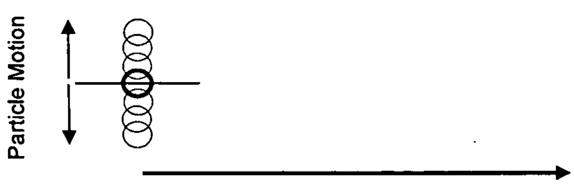

Fig. 1.4

SURFACE WAVE MODE

At the surface of a solid, a complex mode of oscillation can exist in which the particle motion is mainly perpendicular to the direction of propagation as with the shear wave, and partly in the same plane as the direction of propagation as with the compression wave. This mode of propagation is called the 'Surface wave' or 'Rayleigh wave'. Surface waves only affect the surface layer of the solid to a depth of about one wavelength, and have the advantage that they follow the surface contour of the object and only reflect at an abrupt change such as a corner or crack. For the **surface wave, the particle motion is elliptical with the major axis of the ellipse at right angles to the direction of propagation.** This is shown in figure 1.5.

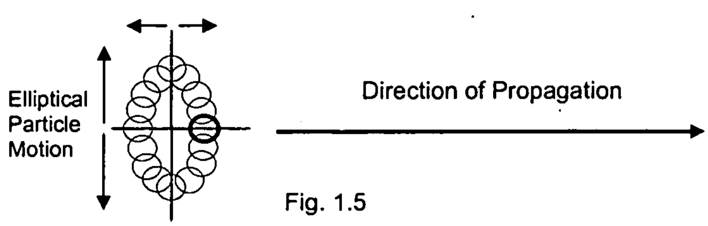

Fig. 1.5

LAMB WAVE MODES

Lamb waves, like Surface waves, propagate parallel to the test surface and have an elliptical particle motion. They occur when the thickness of the test material is only a few wavelengths at the test frequency and where the test piece is of uniform thickness. Lamb waves fill the wall thickness and propagate along the major axis of the component. They can travel several meters in steel, so they can be used for rapid scanning of plate tube and wire. Recent developments for rapid corrosion monitoring in buried pipes use Lamb waves under the name **'Guided Waves'**. The wall of the component flexes so that the sound ripples along the material distorting both surfaces. Figure 1.6 illustrates a type of Lamb wave where the crests of the wave on the near and far surfaces coincide. These are called Symmetrical Lamb Waves. Figure 1.7 shows another type of Lamb wave where the crest on one side coincides with a trough on the other. These are called Asymmetrical Lamb Waves.

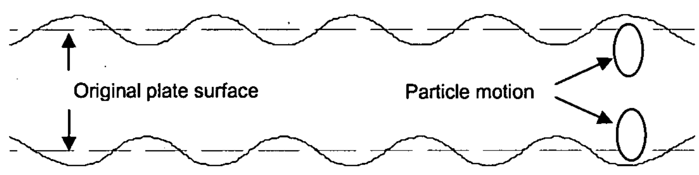

Fig. 1.6

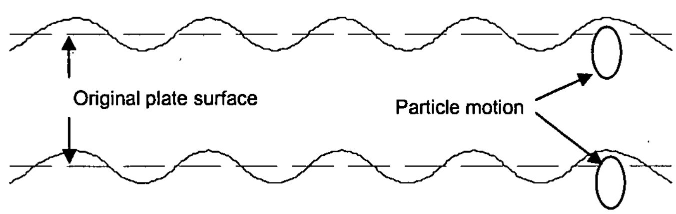

Fig. 1.7

CREEPING (LATERAL) WAVES

There is a special type of compression wave called a **'Creeping'** or **'Lateral'** wave. It sneaks along the surface rather like a surface wave, its use is described later under 'TOFD techniques'.

Reference: - 'Ultrasonic Flaw Detection for Technicians' - Third Edition, June 2004 by J. C. Drury

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